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(54) **Linearizer bridge circuit**

(57) A Ku-band integrated predistortion type linearizer bridge circuit for use in linearizing the performance of a travelling wave tube amplifier (20). The linearizer bridge circuit comprises a linearizer bridge that embodies a phase shifter (23) and a fixed delay (22a) in a linear arm (21a), and a Schottky diode distortion generator (24a) and a PIN diode attenuator (25) in a nonlinear arm (21b). The output of the linearizer bridge is coupled through an output amplifier (32) and an output attenuator (33). The RF output signal from the linearizer bridge circuit is coupled to the travelling wave tube amplifier (20). A control circuit (35) is coupled to the phase shifter (23), the nonlinear Schottky diode distortion generator circuit (24A), and the PIN diode attenuator (25), and receives on and off input command signals, and outputs a bilevel telemetry signal that is used as a mode indicator for ground command control. The control circuit (35) is used to adjust settings of the Schottky diode distortion generator (24A), the phase shifter (23), the PIN diode attenuator (25), and adjust the gain and attenuation settings of the output amplifier (32) and output attenuator (33). All circuits of the linearizer bridge circuit are integrated onto a single alumina substrate (26).
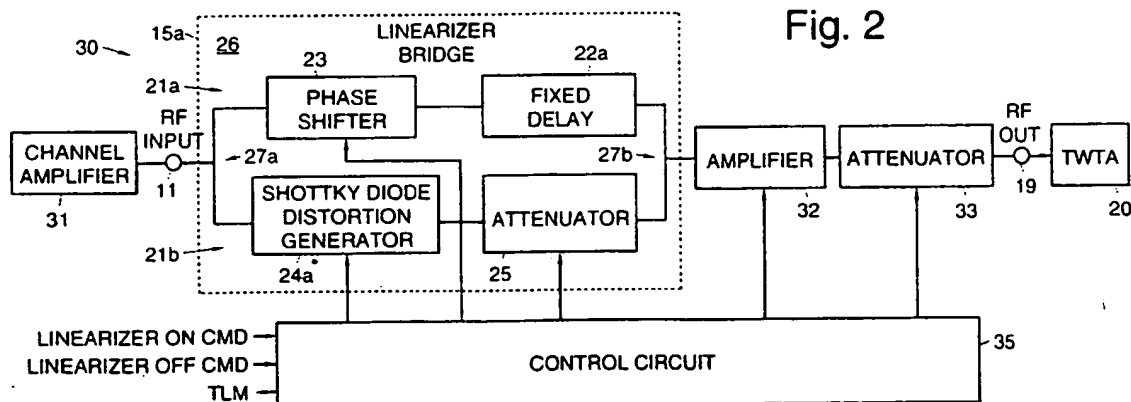
Fig. 2

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Description

The present invention relates generally to travelling wave tube amplifiers (TWTAs), and more particularly, to a linearizer bridge circuit for use with such travelling wave tube amplifiers.

Nippon Electric Corporation (NEC) has developed a linearizer bridge circuit that uses an amplifier as a distortion generator. The NEC linearizer is rated at 4 watts, and weighs 650 grams. ANT Bosch Telecom has developed a linearizer bridge circuit. This system has dimensions of 2.6 centimetres by 1.6 centimetres. Four substrates are required to produce the ANT Bosch Telecom circuit, and it cannot be used to adjust the power transfer curve of a travelling wave tube amplifier. The ANT Bosch Telecom linearizer bridge circuit has an architecture that is similar to the present invention, but is constructed using different components that provide lower performance than the present invention and that operate at higher power levels.

Accordingly, it is an objective of the present invention to provide for an improved linearizer bridge circuit for use with a travelling wave tube amplifier. The present invention also seeks to provide for a high performance Ku-band linearizer bridge circuit that operates at reduced power levels compared to conventional circuits.

According to the invention there is provided a linearizer bridge circuit for use with a travelling wave tube amplifier, the linearizer bridge circuit comprising a linearizer bridge having an RF input for receiving an RF input signal, a linear arm comprising a fixed delay line and a PIN diode phase shifter, a nonlinear arm comprising a nonlinear Schottky diode distortion generator circuit and a PIN diode attenuator, an input coupler for coupling the RF input signal to linear and nonlinear arms of the linearizer bridge and an output coupler for combining the RF signals from the linear and nonlinear arms to provide an RF output signal from the linearizer bridge; an output amplifier coupled to the linearizer bridge for amplifying the RF output signal from linearizer bridge; an output attenuator coupled to the output amplifier for providing an RF output signal from linearizer bridge circuit; and a control circuit coupled to the phase shifter, the nonlinear Schottky diode distortion generator circuit, the PIN diode attenuator, the output amplifier and the output attenuator, for adjusting settings of the Schottky diode distortion generator, the phase shifter, and the PIN diode attenuator, and for adjusting the gain and attenuation settings of the output amplifier and output attenuator control, and wherein proper adjustment of the settings of the Schottky diode distortion generator, the phase shifter, and the PIN diode attenuator, produces a desired gain expansion and phase advance with respect to the power level of the RF input signal applied to the linearizer bridge circuit, which cancels the gain compression and phase lay generated by the travelling wave tube amplifier to improve its linearity performance.

The present invention enables the provision of a Ku-band integrated, compact, size, low cost, pre-distortion type linearizer bridge circuit. The purpose of the linearizer bridge circuit is to improve the linearity performance of a travelling wave tube amplifier with which it is used.

The linearizer bridge circuit is comprised of linear and nonlinear arms. The linear arm comprises a phase shifter and a fixed delay, and the nonlinear arm comprises a Schottky diode distortion generator and a PIN diode attenuator. A control circuit is used to set various bias settings for the circuits of the linearizer bridge circuit. All circuits may be integrated on a single substrate, which may preferably be comprised of alumina. Compact size, lower parts count, reduced assembly and RF tuning and test labour costs are realized with the present linearizer bridge circuit.

By applying a DC bias to the Schottky diode in the distortion generator circuit, the operational power level of the present linearizer bridge circuit is much lower than a conventional linearizer bridge. The major advantage of this feature is that there is less heat dissipation in the circuit and less DC power is required for operation. In addition, lower operational power levels lead to better c/3IM performance in bypass mode.

Another important possibility with the present invention is that, by changing the bias applied to the distortion generator, the phase shifter and the attenuator, instead of making the conventional phase shifter and attenuator adjustments, the present linearizer bridge circuit is capable of adjusting not only phase advance gain expansion, but also gain curvature. This feature leads to the better match between the present linearizer bridge circuit and various travelling wave tube amplifiers with which it is employed.

The linearizer bridge circuit is integrated, in that it is much more compact in size (1.4 x 1.0 centimetres) and has lower power consumption 80 mW) than comparable competing designs. The linearizer bridge circuit also has a relatively wide bandwidth (approximately 3 GHz). The linearizer bridge circuit provides both active and bypass functions. Its power transfer curve may be adjusted for use with different travelling wave tube amplifiers.

In order that the invention and its various other preferred features may be understood more easily some embodiments thereof will now be described by way of example only, with reference to the accompanying drawing, wherein like reference numerals designate like structural elements, and in which:-

Fig. 1 illustrates a conventional linearizer bridge circuit;

Fig. 2 illustrates a linearizer bridge circuit in accordance with the principles of the present invention;

Fig. 3 is a detailed schematic diagram of the linearizer bridge circuit of Fig. 2; and

Fig. 4 is a block diagram of the control circuit employed in the linearizer bridge circuit of Fig. 2.

Referring to the drawing figures. Fig. 1 illustrates a conventional linearizer bridge circuit 10 that may be used with a travelling wave tube amplifier (TWTA) 20. The linearizer bridge circuit 10 depicted in Fig. 1 is representative of one manufactured by ANT Bosch Telecom.

The conventional linearizer bridge circuit 10 has an RF input 11 for receiving an RF input signal that is coupled by way of an input phase shifter 12 and an input variable attenuator 13 to a preamplifier 14. The input variable phase shifter 12 is commandable in order to compensate for the electrical length of the difference between linear and nonlinear arms 21a, 21b of a linearizer bridge 15 and provide for parallel connection of the linearizer bridge 15. The output of the preamplifier 14 is coupled to the linearizer bridge 15. The output of the linearizer bridge 15 is coupled to an output stage 16 that includes an attenuator 17 and an amplifier 18. The output stage 16 has an RF output 19 for providing an RF output signal from the linearizer bridge circuit 10 that is coupled to a travelling wave tube amplifier 20.

The conventional linearizer bridge 15 has separate RF paths 21a, 21b comprising linear and nonlinear arms 21a, 21b, respectively. The linear arm 21a includes a fixed delay line 22 and a phase shifter 23. The nonlinear arm 21b includes a distortion generator circuit 24 and a PIN diode attenuator 25. The PIN diode attenuator 25 is controlled by a resistive circuit containing a thermistor (not shown). The resistor values are optimized to vary the attenuation of the attenuator 25 over the operating temperature range in order to compensate for the gain variation of the linearizer bridge circuit 10 and travelling wave tube amplifier 10. The net gain of the conventional linearizer bridge circuit 10 is about 15 dB, but this value may be adjusted to be 64 dB at a nominal output power by adding preamplifier stages.

Referring now to Fig. 2, it shows an RF block diagram of an improved linearizer bridge circuit 30 in accordance with the principles of the present invention. The linearizer bridge circuit 30 is designed for use with the travelling wave tube amplifier 20. The linearizer bridge circuit 30 is used as an interface between a channel amplifier 31 and the travelling wave tube amplifier 20. The channel amplifier 31 provides an amplified RF input signal to the linearizer bridge circuit 30. The linearizer bridge circuit 30 comprises a linearizer bridge 15a that has an RF input 11 for receiving the amplified RF input signal from the channel amplifier 31. The output of the linearizer bridge 15a is coupled by way of an output amplifier 32 and an output attenuator 33 to an RF output 19. The RF output 19 couples an RF output signal from the linearizer bridge circuit 30 to the travelling wave tube amplifier 20.

The linearizer bridge 15a is a balanced bridge circuit having separate RF paths 21a, 21b comprising linear and nonlinear arms 21a, 21b, respectively. The linear arm 21a comprises a fixed delay line 22a and a phase shifter 23, such as is disclosed in our U.S. Patent

No. 5,317,288. The phase shifter 23 uses PIN diodes (not shown) and has a wide, 360 degree, phase shift range. The nonlinear arm 21b comprises a nonlinear distortion generator circuit 24a that uses Schottky diodes, and a PIN diode attenuator 25. Input and output hybrid couplers 27a, 27b may be used to couple the RF signal to and from the linear and nonlinear arms 21a, 21b of the linearizer badge 15a. All of the circuits of the linearizer bridge 15a are fabricated on a single substrate 26, which may preferably comprise alumina.

A control circuit 35 is coupled to the phase shifter 23, nonlinear Schottky diode distortion generator circuit 24a, and the PIN diode attenuator 25. The control circuit 35 has inputs for receiving on and off input command signals, and an output for generating a bilevel telemetry (TLM) signal. The control circuit 35 is used to adjust the settings of the Schottky diode distortion generator 24a, the phase shifter 23, the PIN diode attenuator 25, and the gain and attenuation settings of the output amplifier 32 and output attenuator 33. The bilevel telemetry (TLM) signal is used as a mode indicator for ground command control.

Referring to Fig. 3, it shows a detailed schematic diagram of the linearizer bridge circuit 30 of Fig. 2. The fixed delay line 22a comprises a bent 50 ohm line, which is employed to compensate the delay between the linear and nonlinear arms 21a, 21b, reduce dispersion and improve the operating frequency band. The phase shifter 23 comprises two pairs of PIN diode reflection attenuators. This circuit provides 360° phase shifting with constant insertion loss. Details of the construction of the phase shifter 23 may be found in U.S. Patent No. 5,317,288, the contents of which are incorporated herein by reference. The nonlinear Schottky diode distortion generator circuit 24a comprises a Lange coupler and two diodes to form a balanced reflection circuit. With properly applying DC bias, this circuit works at low power levels (c-3 dBm) as well as higher power levels. In addition, the gain curve can be easily manipulated by selection of the DC bias level applied to the distortion generator circuit 24a. The PIN diode attenuator 25 comprises six diodes and is used to adjust the output power of the nonlinear arm 21b. In bypass mode, the PIN attenuator provides greater than 35 dB attenuation, which makes the linearizer bridge circuit 30 a linear circuit.

The linearizer bridge circuit 30 operates as follows. The linearizer bridge 15a has two operational modes: active mode and bypass mode. In the active mode, the linearizer bridge 15a functions as a nonlinear circuit that provides up to 10 dB gain expansion with up to 90° phase advance. The gain expansion value and phase advance value are controlled by the phase shifter 23 and PIN diode attenuator 25. In addition, the gain curve can be adjusted by changing the bias supplied to the distortion generator 24a. In the bypass mode, the PIN diode attenuator 25 provides high attenuation in the nonlinear arm 21b. Therefore, the linearizer bridge 15a functions as a linear circuit.

Referring to Fig. 4, there is shown a block diagram of the control circuit 35 employed in the linearizer bridge circuit of Fig. 2. The control circuit 35 comprises a power supply 41 having 8.0 and 8.6 volt outputs that are filtered and regulated by a supply filtering and regulator circuit 42. The linearizer bridge circuit 30 is turned on and off by on and off signals (LIN ON, LIN OFF) input to a command receiver 43 which commands are coupled to a mode latch 44 for the active and bypass modes of the linearizer bridge circuit 30. A reset, power up and mode control circuit 45 is coupled to the mode latch 44 that controls these functions.

A temperature compensation circuit 46 is coupled to a set phase circuit 47, a set distortion circuit 48, a set attenuation 1 circuit 52, and a set attenuation 2 circuit 53. Based upon the output of the temperature compensation circuit 46 the set phase circuit 47, set distortion circuit 48, set attenuation 1 circuit 52, and set attenuation 2 circuit 53 drive voltage controlled current sources 55 coupled thereto. Two voltage controlled current sources 55 provide phase A and phase B drive signals to the phase shifter 23. Two voltage controlled current sources 55 provide distortion A and distortion B drive signals to the Schottky diode distortion generator 24a.

The set attenuation 1 circuit 52 outputs two attenuation values to a first switch 51 which is controlled by the mode latch 44 to selectively drive a voltage controlled current source 55 that provides a first attenuator drive signal (ATTEN 1 DRIVE) that is supplied to the PIN diode attenuator 25. The set attenuation 2 circuit 53 outputs an attenuation value to drive a voltage controlled current source 55 that provides a second attenuator drive signal (ATTEN 2 DRIVE) that is supplied to the output attenuator 33. The output of the mode latch 44 is also coupled to a second switch 54 that selects between a +5 volt and ground signal that generates the mode bilevel telemetry (MODE TLM) signal.

The control circuit 35 provides DC bias for the distortion generator 24a, the PIN diode attenuator 25, and the phase shifter 23 to control the phase advance and gain expansion values. The control circuit 35 also provides DC bias for the output amplifier 32 and output attenuator 33 to control the gain levels thereof. A temperature compensation circuit is employed in the control circuit 35 to compensate for changes of temperature of the distortion generator 24a, attenuators 25, 33 and phase shifter 23 to provide constant performance over a wide temperature range. The control circuit 35 switches the linearizer bridge 15a between active and bypass modes, and provides the bilevel telemetry signal as a mode indicator for ground command control.

By properly adjusting the settings of the Schottky diode distortion generator 24a, the phase shifter 23, and the PIN diode attenuator 25, desired gain expansion and phase advance with respect to the power level of the RF input signal applied to the linearizer bridge circuit 30 is achieved. This cancels the gain compression and phase lag generated by the travelling wave tube amplifier 20

and therefore improves its linearity performance (third-order intermodulation, phase, and AM/PM conversion).

The linearizer bridge circuit 30 operates in active and bypass modes. In bypass mode, the attenuation of the nonlinear arm 21b is increased to greater than 30 dB, forcing the RF input signal to only pass through the linear arm 21a. Therefore, the linearizer bridge circuit 15 provides both active and bypass mode functions.

An integrated Ku-band linearizer bridge circuit 30 has been reduced to practice and is used with a travelling wave tube amplifier 20. The phase shifter 23, Schottky diode distortion generator 24a, attenuator 25, and delay line 22 are fabricated on a single alumina substrate 26. The Ku-band linearizer bridge circuit 30 that was reduced to practice has the advantages of compact size, a relatively small number of circuits, and may be manufactured with reduced assembly and RF tuning and setting labour compared to a currently used multi-carrier amplifier design.

The reduced to practice embodiment of the linearizer bridge circuit 30 has an operating frequency of 19.1 GHz to 19.2 GHz, its gain is about 15 dB, and its power consumption is about 0.95 watt. The mass of the linearizer bridge circuit 30 is about 257 grams and has dimensions of 18 centimetres by 3.5 centimetres by 3.5 centimetres. The DC input voltage provided to the linearizer bridge circuit 30 may be between ± 7 volts.

Thus, an improved linearizer bridge circuit for use with travelling wave tube amplifiers has been disclosed. It is to be understood that the described embodiment is merely illustrative of some of the many specific embodiments which represent applications of the principles of the present invention.

Claims

1. A linearizer bridge circuit for use with a travelling wave tube amplifier, the linearizer bridge circuit comprising a linearizer bridge (15a) having an RF input for receiving an RF input signal, a linear arm (21a) comprising a fixed delay line (22a) and a PIN diode phase shifter (23), a nonlinear arm (21B) comprising a nonlinear Schottky diode distortion generator circuit (24A) and a PIN diode attenuator (25), an input coupler (27a) for coupling the RF input signal to linear and nonlinear arms of the linearizer bridge and an output coupler (27b) for combining the RF signals from the linear and nonlinear arms to provide an RF output signal from the linearizer bridge:

   an output amplifier (32) coupled to the linearizer bridge for amplifying the RF output signal from linearizer bridge: an output attenuator (33) coupled to the output amplifier (32) for providing an RF output signal from linearizer bridge circuit: and a control circuit (35) coupled to the phase shifter (23), the nonlinear Schottky diode distortion generator circuit

(24a). the PIN diode attenuator (25). the output amplifier (32) and the output attenuator (33), for adjusting settings of the Schottky diode distortion generator (24a), the phase shifter (23), and the PIN diode attenuator (25), and for adjusting the gain and attenuation settings of the output amplifier (32) and output attenuator (33) control, and wherein proper adjustment of the settings of the Schottky diode distortion generator (24a), the phase shifter (23), and the PIN diode attenuator (25), produces a desired gain expansion and phase advance with respect to the power level of the RF input signal applied to the linearizer bridge circuit, which cancels the gain compression and phase lay generated by the travelling wave tube amplifier to improve its linearity performance.

2. A linearizer bridge circuit as claimed in Claim 1, wherein the linearizer bridge circuit operates in active and bypass modes.

3. A linearizer bridge circuit as claimed in Claim 2 wherein, when the linearizer bridge circuit operates in bypass mode, the attenuation of the nonlinear arm (21b) is increased to greater than 35 dB. forcing the RF input signal to only pass through the linear arm (21a).

4. A linearizer bridge circuit as claimed in any one of the preceding claims, wherein the control circuit provides commands to switch between active mode and bypass mode, to control temperature compensation and adjust gain curves of the linearizer bridge circuit.

5. A linearizer bridge circuit as claimed in any one of the preceding claims, wherein the linearizer bridge is fabricated on a single substrate (26).

6. A linearizer bridge circuit as claimed in Claim 5, wherein the substrate (26) comprises an alumina substrate.

7. A linearizer bridge circuit as claimed in any one of the preceding claims, wherein the control circuit (35) processes on and off input command signals that turn the linearizer bridge circuit on and off.

8. A linearizer bridge circuit as claimed in any one of the preceding claims, wherein the control circuit (35) outputs a bilevel telemetry signal that provides a mode indicator for ground command control.
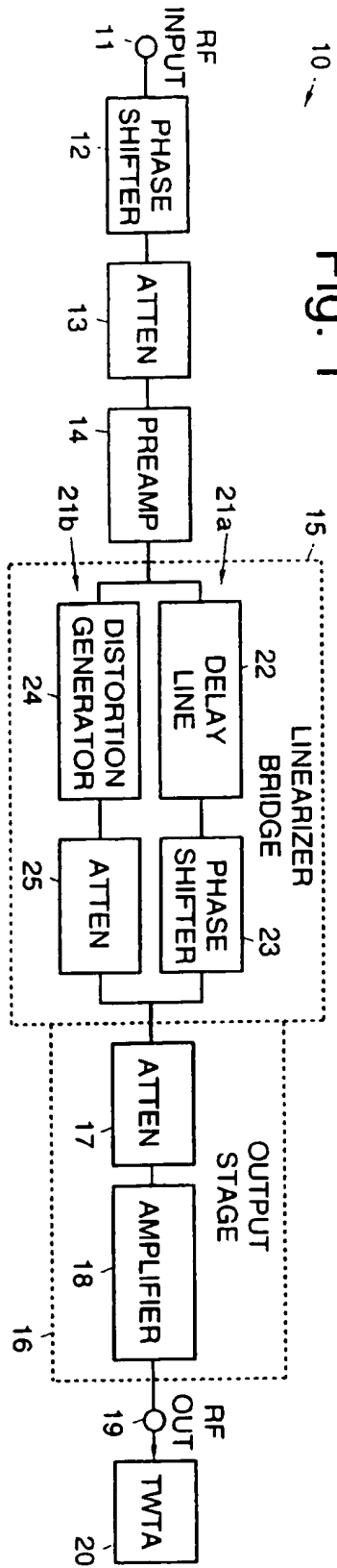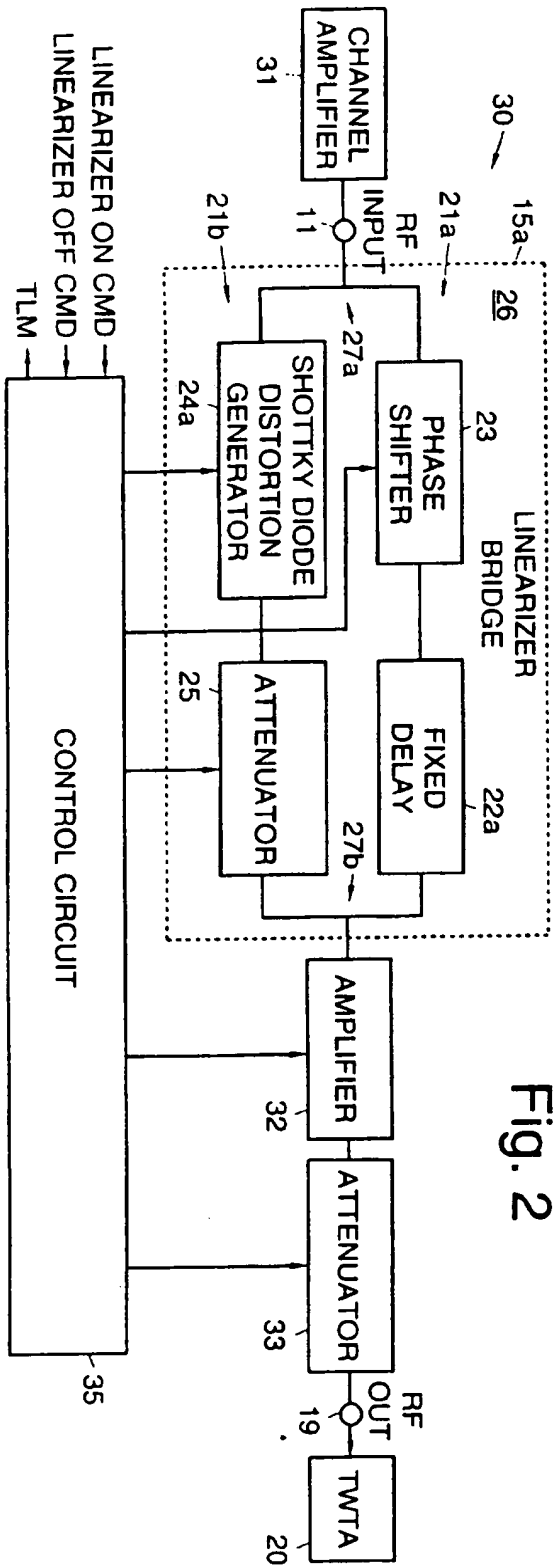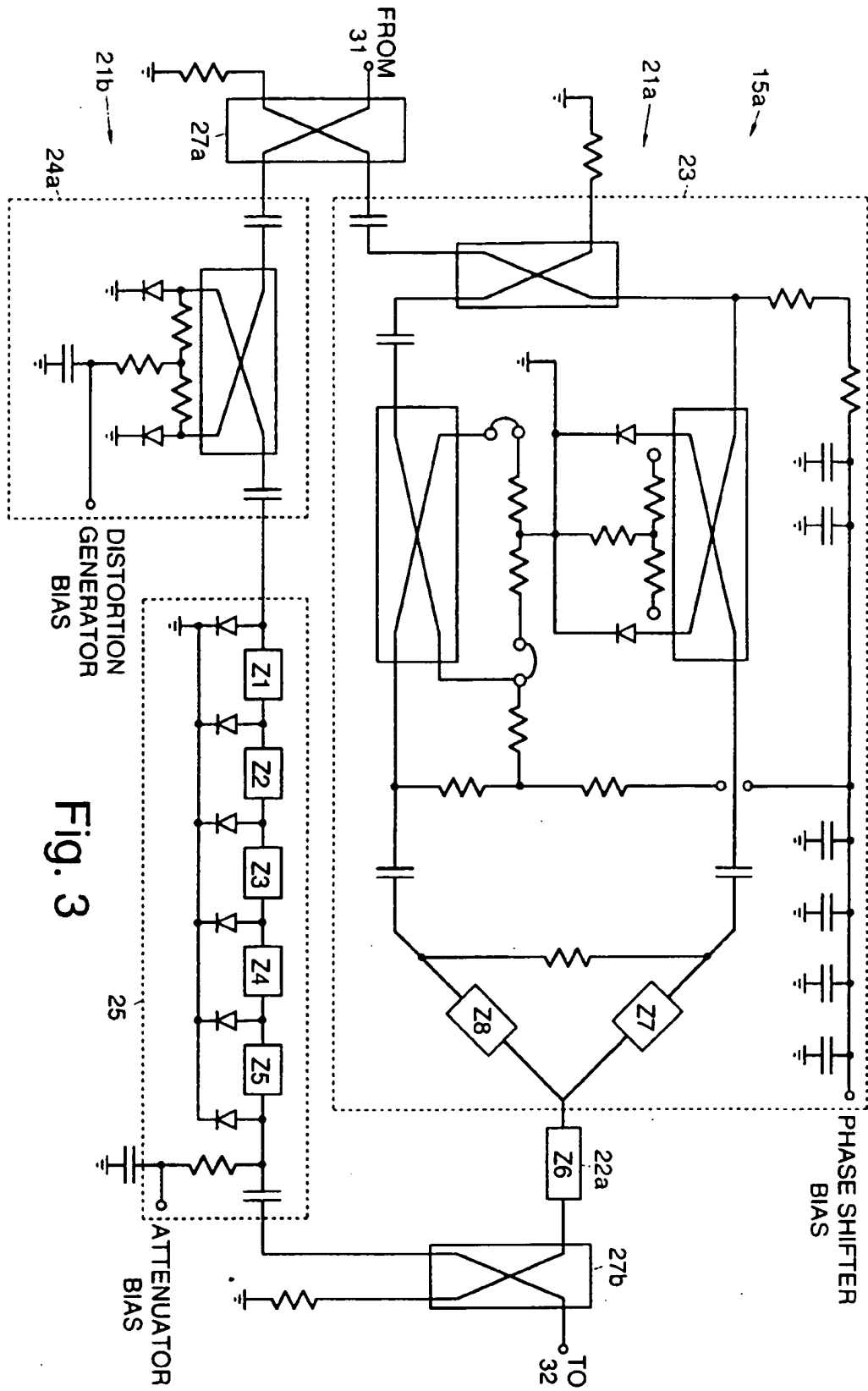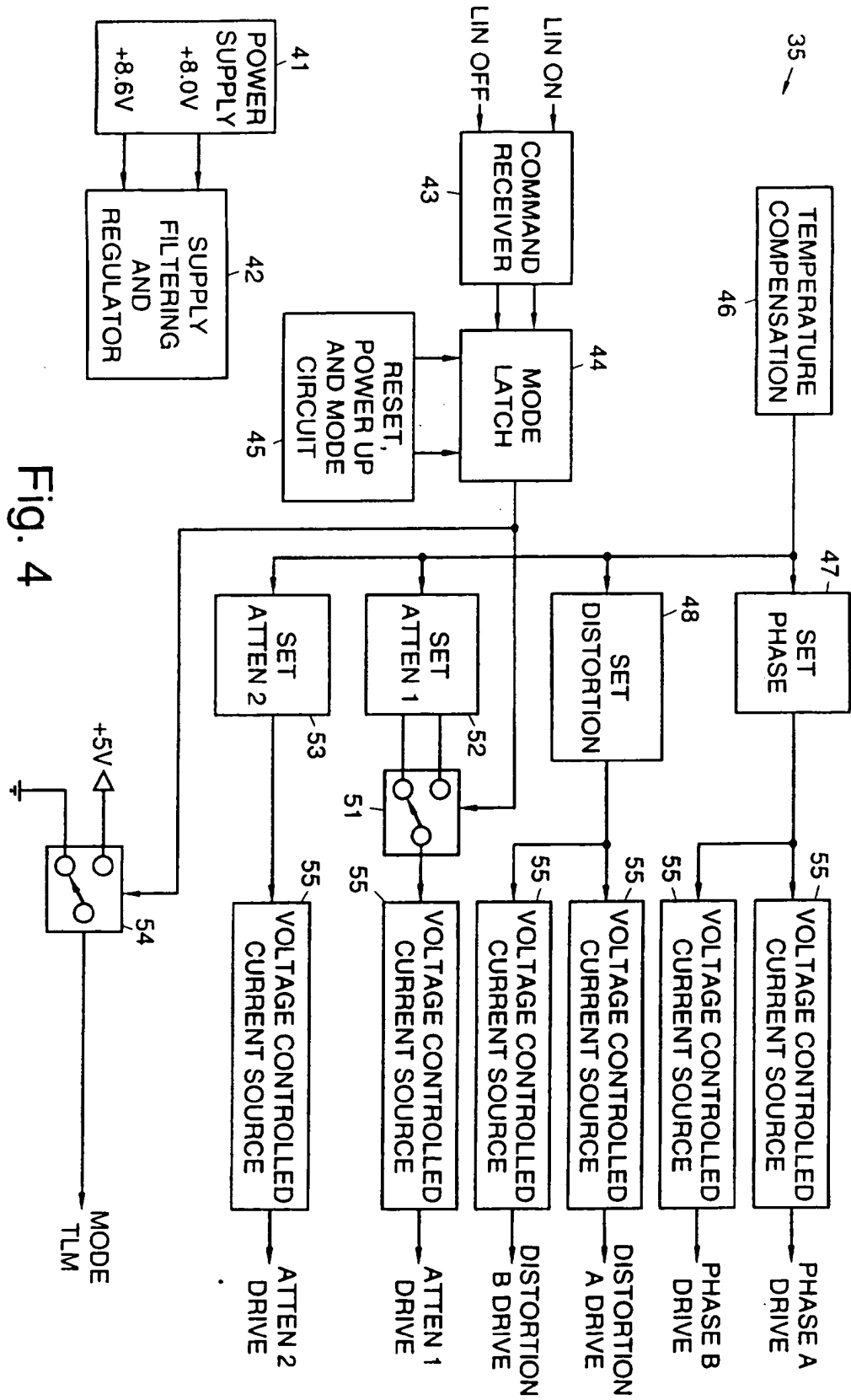
Fig. 1

Fig. 2

Fig. 3

Fig. 4

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<tr><td colspan="2">))) European Patent Office</td><td>EUROPEAN SEARCH REPORT</td><td>Application Number
EP 97 30 8898</td></tr>
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DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
A	ABDEL-MESSIAH KHILLA: "LINEARISIERER FUR WANDERFELDROHREN IN ZUKUNFTIGEN NACHRICHTENSATELLITEN UND BODENSTATIONEN" FREQUENZ, vol. 48, no. 9/10, 1 September 1994, pages 227-232, XP000479975 * page 228, right-hand column - page 231, right-hand column; figures 2,4,5 *	1,5,6,8	H03F1/32
A	US 5 304 944 A (COPELAND WILBERT ET AL) * abstract; figures 1,2 *	1	
D,A	US 5 317 288 A (YUNG MING L ET AL) * abstract; figure 2 *	1	
A	EP 0 544 117 A (NIPPON ELECTRIC CO) * page 4, line 42 - line 45; figure 4 *	2,4,7	

TECHNICAL FIELDS SEARCHED (Int.Cl.6)

H03F

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	3 February 1998	Tyberghien, G

CATEGORY OF CITED DOCUMENTS

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